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Patentanmeldung Nr. Patent application No. Demande de brevet n°

03101911.0

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Anmeldung Nr:
Application no.: 03101911.0
Demande no:

Anmeldetag:
Date of filing: 26.06.03
Date de dépôt:

Anmelder/Applicant(s)/Demandeur(s):

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Bezeichnung der Erfindung/Title of the invention/Titre de l'invention:
(Falls die Bezeichnung der Erfindung nicht angegeben ist, siehe Beschreibung.
If no title is shown please refer to the description.
Si aucun titre n'est indiqué se referer à la description.)

Electronic device and module

In Anspruch genommene Prioriät(en) / Priority(ies) claimed /Priorité(s) revendiquée(s)
Staat/Tag/Aktenzeichen/State/Date/File no./Pays/Date/Numéro de dépôt:

Internationale Patentklassifikation/International Patent Classification/
Classification internationale des brevets:

H01P/

Am Anmeldetag benannte Vertragstaaten/Contracting states designated at date of filing/Etats contractants désignées lors du dépôt:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HU IE IT LU MC NL
PT RO SE SI SK TR LI

Electronic device and module

The invention relates to an electronic device comprising a microelectromechanical system (MEMS) element, the element having a first and a second electrode and an intermediate beam with a first and a second opposite conductive side faces, the first side face facing the first electrode and the second side face facing the second electrode, which beam is movable to and from the first and the second electrode by application of a driving voltage.

The invention further relates to a module comprising such device.

Such an electronic device is for instance known from WO-A 00/52722. The known device is a MEMS element in which the electrodes and the beam are provided in planes substantially parallel to a substrate. The intermediate beam is herein a laminate comprising between the two conductive surfaces a first insulating layer, a cantilever beam and a second insulating layer. The side faces are used as control surfaces and provide the capability to use separate driving functions for the top and the bottom switch structures. This allows for simultaneous push and pull operation for enhanced speed. By placing both conductive surfaces at the ground common potential, an electrostatic shield between the signal currents at the cantilever beam and the control signals providing the coulomb forces are provided. This structure thus provides signal isolation enhancement when compared to simpler cantilever beam structures.

It is a disadvantage of the known electronic device that it has an insufficient dynamic range for applications in the RF domain.

It is therefore a first object of the invention to provide an electronic device of the kind mentioned in the opening paragraph with an improved dynamic range.

This object is achieved in that the first electrode and the first conductive side face of the beam form with an intermediate dielectric a first tunable capacitor that is connected in a signal path between an input and an output, and that the second electrode and

the second side face of the beam form with an intermediate dielectric a second tunable capacitor, that is coupled from the signal path to ground.

Surprisingly it has been found that the MEMS element with this connection, wherein one capacitor is in the signal path and the other is connected to ground, provides a improved dynamic range. This connection is in fact a combination of the shunt and the series configuration of conventional MEMS capacitors and switch without any intermediate beam. The element of the invention leads in comparison therewith to a significant higher isolation for a given insertion loss. Whereas conventional RF MEMS capacitive switch show an isolation of –20dB for –0.1 dB of insertion loss, the element of the invention shows an isolation of –32 dB at the same insertion loss. This improved performance is moreover achieved without increasing the overall device dimensions.

In a first embodiment the beam is embodied as a third electrode. Thus, a much simpler construction for the beam is used than in the state of the art. This has as a first advantage that it has a low stiffness and thus allows for a very low actuation voltages, preferably below the battery voltages of a few volts. It has as second advantage that the manufacturability is improved. In fact, the element of this embodiment can be realized in a thin film process.

In a further embodiment, the surface area of the second electrode is larger than that of the first electrode. Herewith the switch performance can be tuned and an even higher isolation can be realized. There are various ways of modifying the surface are of the second electrode; it could be smaller than the third electrode and the first electrode; it could have a limited overlap with the third electrode only. It is however preferable that the second electrode is subdivided into individual segments. Such segmentation allows that the third electrode falls within the boundaries of the second electrode. This allows for a good design of the surface area ratio between the first and the second electrode. Furthermore, it creates space under the third electrode. This has the benefit that the sticking problem of the third electrode to the second electrode is diminishing. If desired it could be diminished actively, using flow of air, or by filling the spaces between the segments with another material that does not show any attracting interaction with the material of the third electrode. With such embodiment, the isolation can be improved to –38 dB. The effect of segmentation is considerable in total; for a fourfold increase of the capacitor coupled to ground (with respect to the series capacitor), the dynamic range is enlarged tenfold.

It is preferred for this construction that the MEMS element is of the horizontal type, e.g. that the first and second electrode are present in planes that are substantially

parallel oriented with respect to the substrate. The term substantially parallel should be seen in comparison to the vertical type of MEMS elements, which is for instance used in accerelometers.

It is further preferred that the second electrode, that is connected to ground, is present on the substrate surface. This allows an easy design of the ground, such that the ground has also a real ground potential. Furthermore, it is more easy to subdivide the second electrode in individual segments if it is present on the substrate.

It is even more preferred that the first electrode is embodied in a layer with a spring constant that is substantially larger than the spring constant of the beam. The first electrode is generally constructed in a bridge like form. For a stable operation, the movement of the bridge induced by the driving voltage should me negligible compared to the beam movement. Furthermore, , there is a risk of resonating behavior of this first electrode if the beam is moved upwards or downwards if the bridge is not stiff enough. This is undesired. Increasing the stiffness of the layer of the first electrode takes away this problem. The stiffness of the layer can increased by increasing the thickness of the layer, for instance to the order of 1-10 microns, or by using a material with a higher stiffness that nevertheless has good electrical conductivity. Examples hereof are alloys of Al and Ti and of Al and Cu, with preferably 1-5% of the alloying element.

The term conductive side faces should not exclude the case that these faces are covered by a thin layer of insulating material. In fact, if Al is used for the third electrode, a native oxide of Al_2O_3 will be formed automatically. This is particularly preferred in the case that the first and second electrode not only function as signal electrodes, but also as actuation electrodes. Also the third electrode can be given both functions The dielectric serves then as a protection to prevent short-circuitry.

The first and second tunable capacitors can be applied both as capacitors and as switches. If the capacitive behavior towards ground is desired, a dielectric layer can be present on top of the second electrode. A suitable dielectric is for instance silicon nitride, tantalum oxide etc.

It is furthermore an object of the invention to provide an electronic device of the kind mentioned in the opening paragraph, that is easily manufacturable. This object is realized in that he first and second conductive side faces are part of the same electrically conductive layer being a third electrode. Herewith, use can be made of a thin-film process with three metal layers. Such a thin-film process can be more easily controlled. The

manufacture of a MEMS element in such a process is described in the non-prepublished application EP 02079467.3 (PHNL021052), which is herein included by reference.

It is an advantage of the present invention, that this MEMS element with three electrodes has good electrical performance, particularly if connected in the further shown manner.

It is a further advantage, that this MEMS element is suitable for integration in a process in which also other passive elements can be manufactured. Inductors can be defined in the layer in which also the first electrode is defined, and which is given a larger thickness and/or another material composition, so as to increase its stiffness in comparison to the third electrode. Electrodes of thin film capacitors can be defined in the same layers as the second and the third electrodes. The dielectric layer thereof could even cover the second electrode of the MEMS element, if it is to be used specifically as a tunable capacitor instead of a switch. The process of manufacture such passive integration process with good capacitors, good inductors and good interconnects that is applicable in the RF domain, is known from US6538874, that is included herein by reference.

The implementations and embodiments as described above are also applicable here.

The substrate of this MEMS process is preferably insulating or semi-insulating. Examples of such substrates includes GaAs, glass, alumina, and ceramics with or without internal conductors. The choice of the ceramic may optimize the thermal expansion behavior. It is however preferred to use high-ohmic silicon as the substrate. Both polycrystalline silicon and high-ohmic monocrystalline silicon, that is made high ohmic by implantation with ions such as He or Ar, can be used. Also a silicon substrate with an amorphous top layer is very suitable.

The electronic devices of the inventions are very suitable for use in impedance matching. Particularly preferred is the application of impedance matching networks for the antenna in mobile phones, wherein the antenna switches for switching between the receive and the transmittal paths and between the different frequency bands are included. However, the impedance matching is also suitable at other locations, for instance at the power amplifier, at the transceiver.

The available prior art does not teach the present inventions.

- Both EP1093142 and WO00/52722 show structures in which the intermediate electrode is a laminate of several layers. That does not enable simple manufacturing on an industrial scale.

- US2002/0153236 shows a structure with an intermediate electrode (Fig. 20), but this is a vertical MEMS construction (as used for sensors), not a horizontal structure.

- US6,310,526 describes a structure with a magnetic actuation principle. Herein the MEMS is a switch between an input and two output microstrips. Thickness values are given (0,5-10 um) for the microstrips, but this is dependent on the microstrip behavior solely. Neither is given the suggestion to put one of the two outputs to ground, and use the switches as capacitors as well, nor is shown the manufacture of the device.

- US2003/0048036 shows a MEMS structure that operates on the basis of comb-finger sensor/actuator. The patent discusses at the beginning the electrostatic MEMS structure used in the invention, and states clearly the differences to the comb-finger sensor/actuator.

These and other aspects of the invention will be further elucidated with reference to the Figures.

Fig. 1 A) Cross-section of a switchable MEM capacitor. The freestanding top electrode is pulled-down by applying a DC voltage between the bottom- and top electrode. B) The MEM device can either be used in shunt or series configuration.

Fig. 2 Cross-section of a bi-stable MEM capacitor. The devices consists of three electrodes of which two are suspended above the substrate. The switching action is performed by pulling the middle electrode to either the top- or bottom electrode. The pulling action is established by applying a DC voltage between the moving electrode and one of the fixed electrodes.

Fig. 3 A circuit that is realized using the bi-stable MEM capacitor. It can be seen that the new device layout integrates the shunt- and series configuration into one device.

Fig. 4 The bi-stable switch leads to a significant higher isolation for a given insertion loss. The switch performance can be further optimized by changing the ratio of the bottom- and top electrode areas. In this case, by making $C_2=2.C_1$. The data are calculated for a frequency of 900 MHz (GSM band) and gap between top and bottom electrode of 2.4 m. The electrode length equals the square root of the electrode area (square electrodes are assumed).

Fig. 5 The electrode area ratio C_2/C_1 can be altered by segmenting the bottom electrode.

Fig. 6 Manufacturing flow is depicted for realizing the bi-stable switch. A stack of metal layers (e.g. Al) and sacrificial layers (e.g. PECVD SiN_x) is deposited. Next, the sacrificial layers are removed using e.g. CF_4 plasma. The metal layers both serve as actuation- as well as signal electrodes. A dielectric layer covering the metal layers is used to avoid a short circuit between the electrodes when the middle electrode is pulled to one of the fixed electrodes. When Al is used for defining the electrodes the native Al-oxide functions as the dielectric.

CLAIMS:

1. Electronic device comprising a microelectromechanical system (MEMS) element, the element having a first and a second electrode and an intermediate beam with a first and a second opposite conductive side faces, the first side face facing the first electrode and the second side face facing the second electrode, which beam is movable to and from the first and the second electrode by application of a driving voltage,

wherein the first electrode and the first conductive side face of the beam form with an intermediate dielectric a first tunable capacitor that is connected in a signal path between an input and an output, and

the second electrode and the second side face of the beam form with an intermediate dielectric a second tunable capacitor, that is coupled from the signal path to ground.

2. An electronic device as claimed in claim 1, wherein the beam is embodied as a third electrode.

3. An electronic device as claimed in claim 1 or 2, wherein the first electrode has a surface area that is larger than that of the second electrode.

4. An electronic device as claimed in claim 3, wherein the second electrode is subdivided into individual segments.

5. An electronic device as claimed in claim 1 or 2, wherein the electrodes are present in planes substantially parallel to a substrate.

6. An electronic device as claimed in claim 5, wherein the second electrode is present between the beam and the substrate and the first electrode is embodied in a layer with a spring constant that is substantially larger than the spring constant of the beam.

7. An electronic device as claimed in claim 1, wherein the conductive side faces of the beam are connected to the input and the first electrode functions as the output.

8. An electronic device as claimed in claim 2, wherein the third electrode is provided layer with an electrically insulating layer at both the first and the second side faces.

9. Electronic device comprising a microelectromechanical system (MEMS) element on a substrate, the element having a first and a second electrode, which electrodes are provided in planes that are substantially parallel to the substrate, in between of which first and second electrode an intermediate beam with a first and a second opposite conductive side faces is present, the first side face facing the first electrode and the second side face facing the second electrode, which beam is movable to and from the first and the second electrode by application of a driving voltage, characterized in that the first and second conductive side faces are part of the same electrically conductive layer being a third electrode.

10. An electronic device as claimed in claim 9, wherein the second electrode is present between the third electrode and the substrate and the first electrode is embodied in a layer with a spring constant that is substantially larger than the spring constant of the third electrode.

11. An electronic device as claimed in claim 9 or 10, wherein the second electrode is provided with a surface area that is smaller than that of the first electrode.

12. An electronic device as claimed in claim 11, wherein the second electrode is subdivided into individual segments

13. An electronic device as claimed in claim 6 or 10, wherein the first electrode is defined in a layer in which also an inductor is defined.

14. An electronic device as claimed in claim 2 or 9, wherein the first and the third electrodes are defined in layers, in which also the electrodes of a thin film capacitor are defined.

15. An electronic device as claimed in claim 6 or 10, characterized in that the second electrode is constructed as a bridge with supporting spacers on the substrate.

16. An electronic device as claimed in claim 1 or 9 wherein the MEMS element is part of an impedance matching network

17. A front end module providing with a power amplifier and the electronic device according to any of the preceding claims.

18. Use of the electronic device for RF applications, wherein the beam is driven by a driving voltage towards or from the first electrode.

ABSTRACT:

The MEMS element of the invention has a first, a second and an intermediate third electrode. It is given an increased dynamic range in that the tunable capacitor constituted by the first and the third electrode is provided in the signal path between input and output, and that the tunable capacitor constituted by the second and third electrode is provided between the signal path and ground. The MEMS element of the invention is very suitable for integration in a network of passive components.

Fig. 5

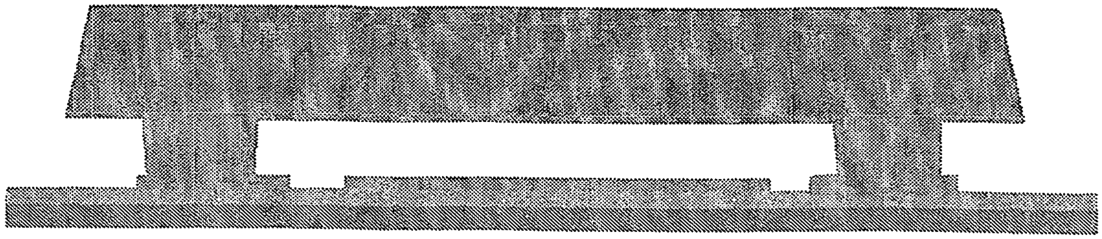

FIG.1A

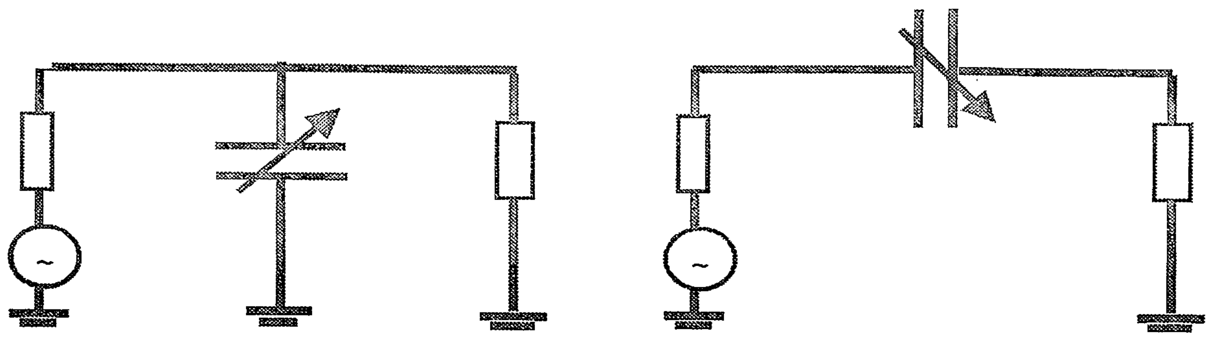

FIG.1B

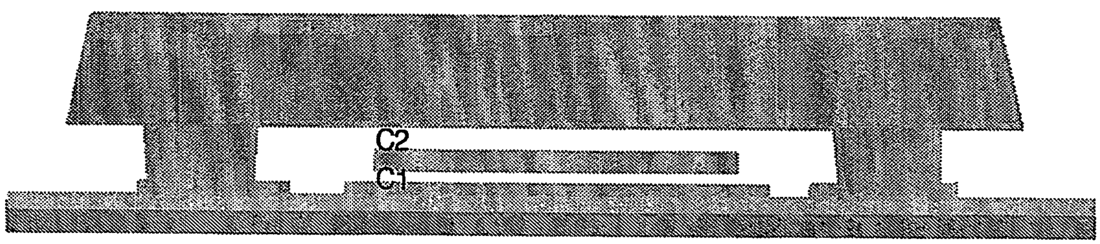

FIG.2

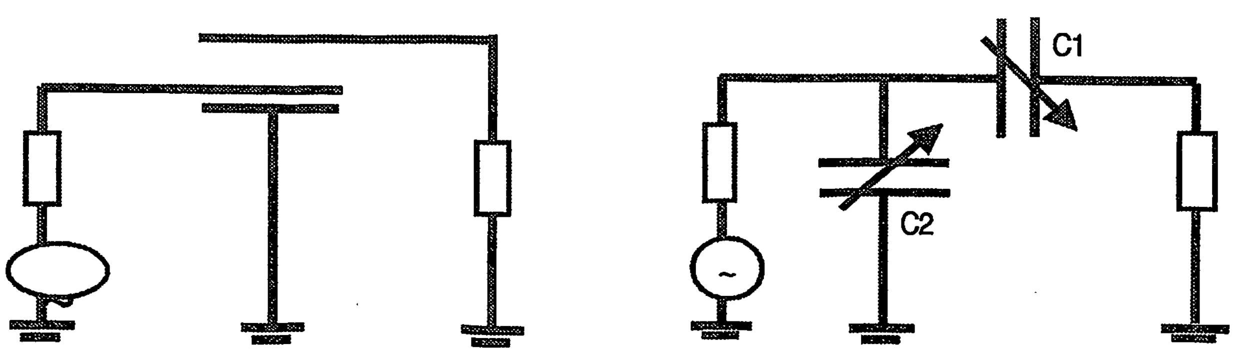

FIG.3

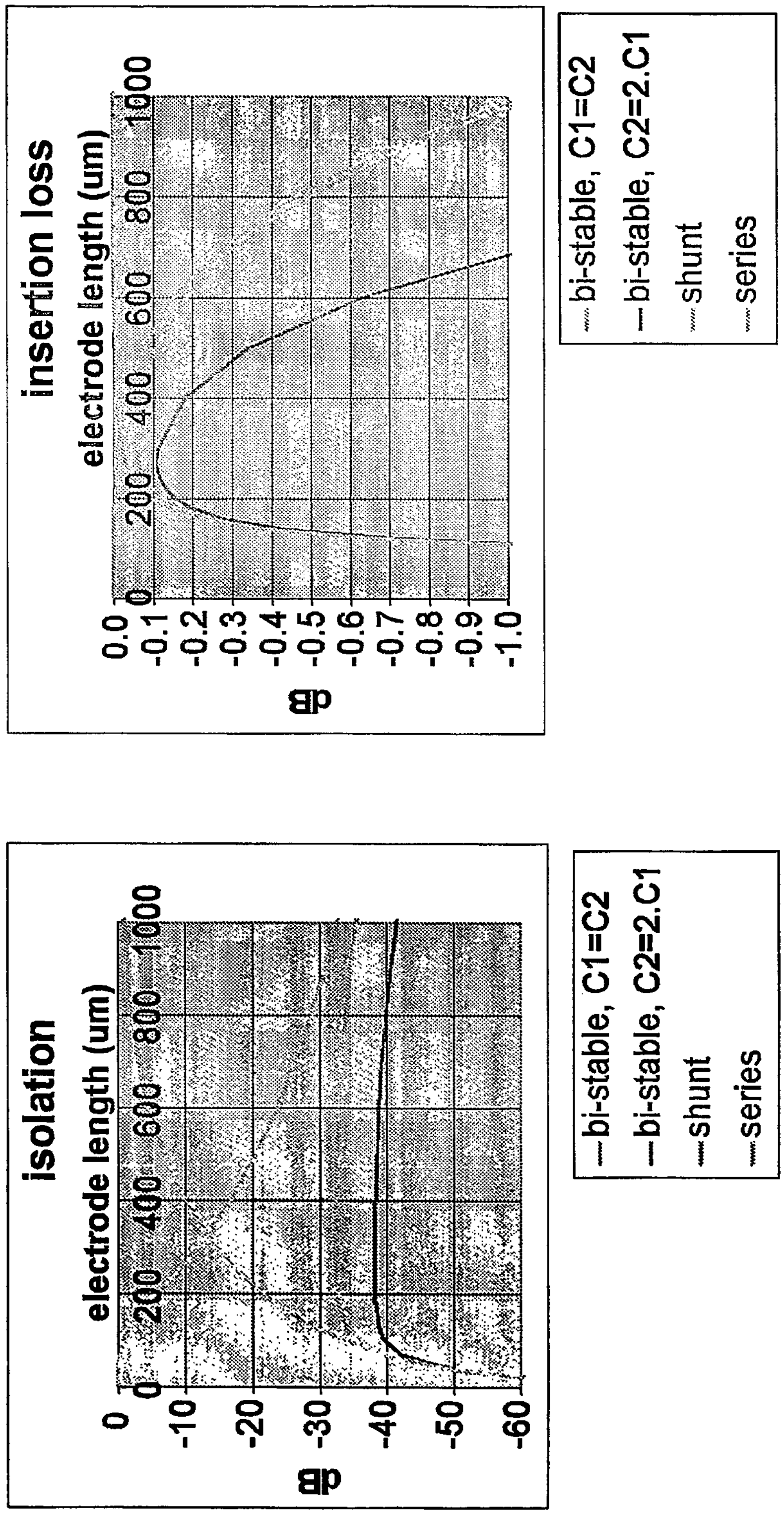
isolation
electrode length (um)
0
200
400
600
800
1000
dB
0
-10
-20
-30
-40
-50
-60
—bi-stable, C1=C2
—bi-stable, C2=2.C1
—shunt
—series
insertion loss
electrode length (um)
0
200
400
600
800
1000
dB
0.0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1.0
—bi-stable, C1=C2
—bi-stable, C2=2.C1
—shunt
—series

FIG.4

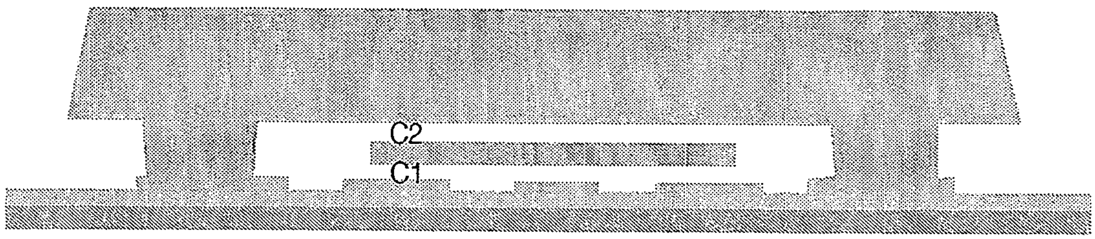

FIG.5

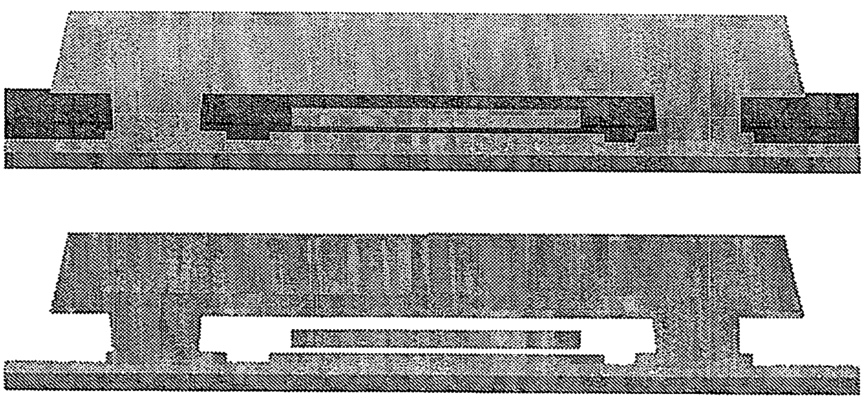

FIG.6

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